



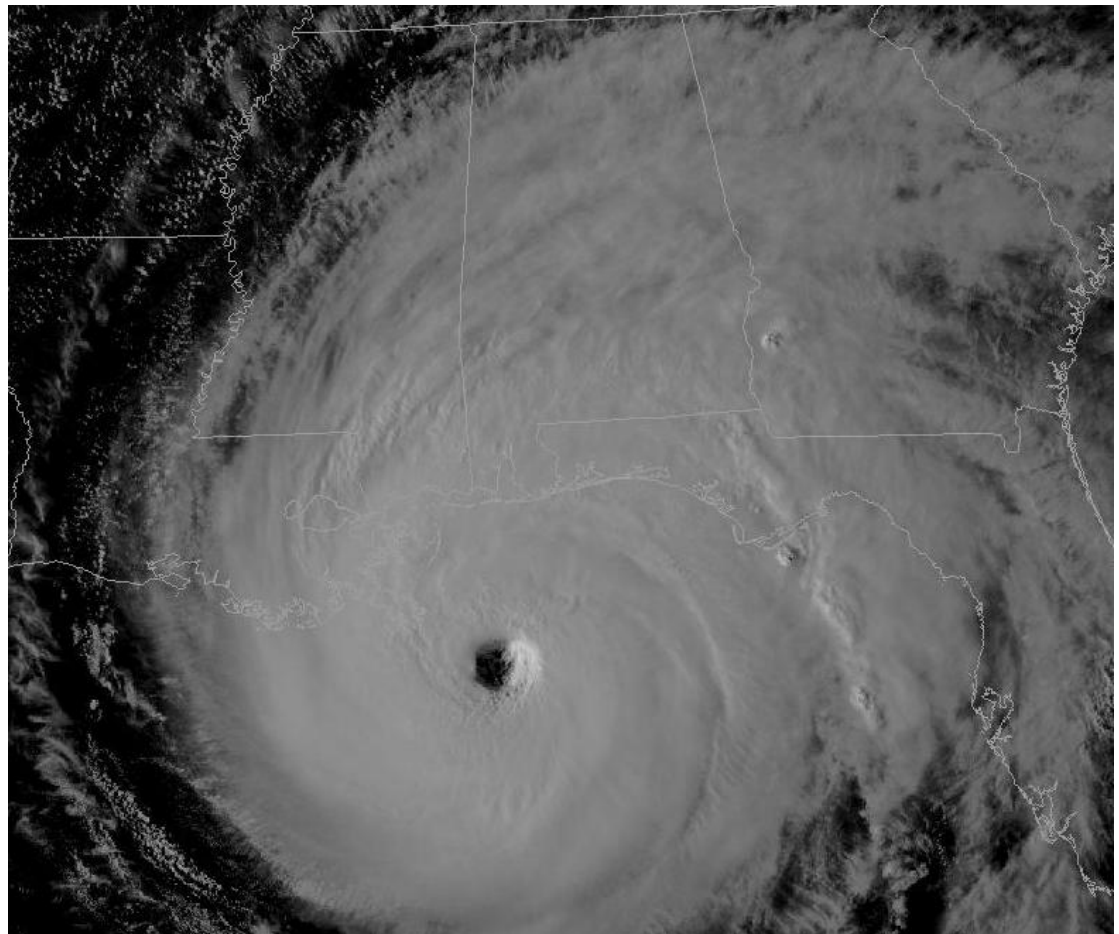
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Shore Protection Assessment Program

Hurricane Ivan Nearshore Wave Data, Perdido Pass, Alabama

Margaret A. Sabol, James P. McKinney, and Linda Lillycrop

August 2009



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Abstract: In November 2001, the U.S. Army Engineer District, Mobile, funded the Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center (ERDC) to deploy a bottom mounted wave gage in 30 ft of water approximately 1 mile offshore of Perdido Pass, AL. On 16 September 2004, Hurricane Ivan made landfall 20 miles west of Perdido Pass as a category 3 hurricane with 120 miles-per-hour maximum winds. The gage was located and recovered in August 2007 by Emerald Ocean Engineering and returned to ERDC, and the data were found to be intact. Nearshore waves from Hurricane Ivan were recorded by the wave gage. Highest significant wave height of 5.11 m occurred at 0500 GMT on 16 September 2004, with a peak period of 12.8 sec.

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Preface

This report is a deliverable product of the Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC) reimbursable project for collecting near real-time wave data at Perdido Pass, AL, performed by the Field Data Collection and Analysis Branch (FDCAB), Flood and Storm Protection Division (FSPD), CHL. The project was funded by the U.S. Army Engineer District, Mobile. The project manager was William D. (Sam) Corson (retired). The project began in the Coastal Engineering Branch under the leadership of Dr. Yen-Hsi Chu. Dr. Chu, retired, and branch leadership was taken over by William Birkemeier. CHL underwent a reorganization and the branch became the FDCAB. Branch leadership changed to Sam Corson (Acting Branch Chief), then to Dr. Brad Guay (former Branch Chief), then to Mark Null (former Branch Chief), and is currently under the leadership of James P. McKinney (Branch Chief) and Bruce A. Ebersole, Chief, FSPD. This report was published through the Shore Protection Assessment Program. Program Manager was William R. Curtis.

This report was prepared by Margaret Sabol (FDCAB, currently in the CHL Executive Office), James P. McKinney (Field Data Collection and Analysis Branch) and Linda Lillycrop (U.S. Army Engineer District, Mobile, currently in the Coastal Engineering Branch, Navigation Division, CHL).

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	0.404685642	hectares
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
miles (U.S. statute)	1.609	kilometers

1 Project Description

Introduction

The U.S. Army Engineer District, Mobile (hereafter, the Mobile District) is responsible for maintaining the Perdido Pass, AL, a federally authorized navigation channel and associated jetties. Perdido Pass is located in Orange Beach, AL, 30 miles east of Mobile Bay, AL. The project provides navigation access between the Gulf of Mexico and Perdido Bay, AL (Figure 1), and includes a 12×150 -ft entrance channel and a main 9×100 -ft channel leading to twin 9×100 -ft channels into Perdido Bay.

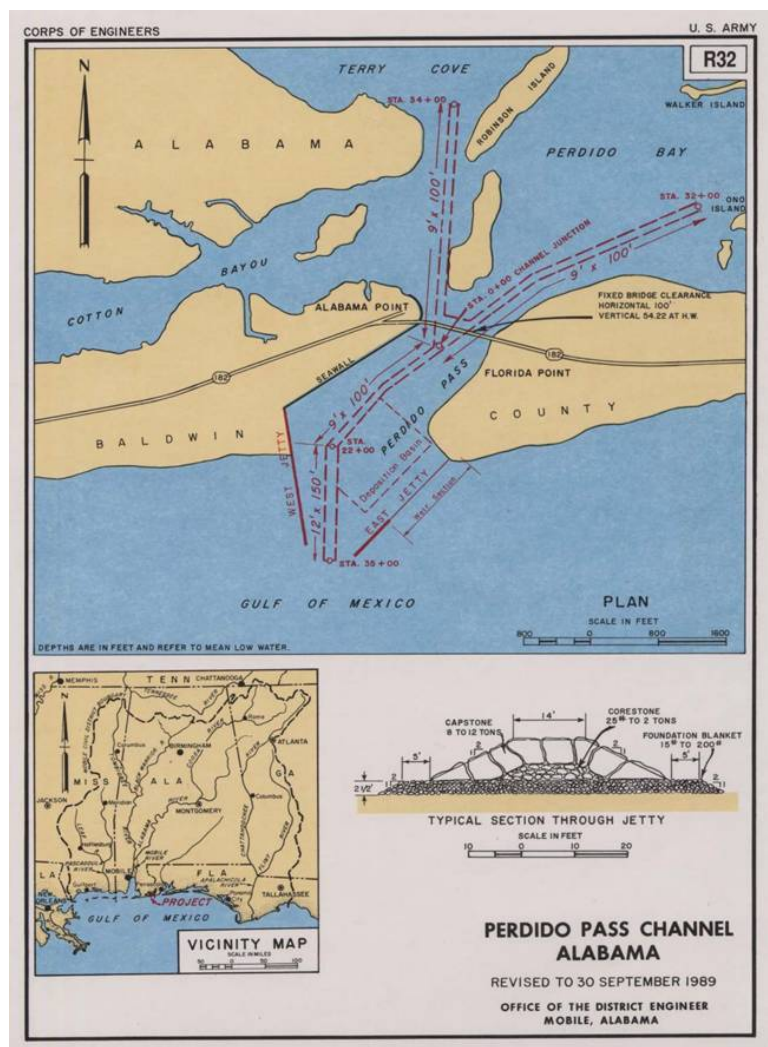


Figure 1. Perdido Pass, AL, location and map.

Since 1971, more than 6 million cu yd of sediment has been dredged from the navigation channels and placed in various disposal areas, with much of the sandy material either removed from the littoral system or placed in areas resulting in a slow return of the sediment to the littoral system. Historically, maintenance dredging is conducted on a 2-3 year cycle, and dredging volumes have ranged from 150,000 to 750,000 cu yd.

Regional Sediment Management initiative

To be consistent with the U.S. Army Corps of Engineers (USACE) Regional Sediment Management (RSM) practices, the Corps conducted a dredging and disposal demonstration to improve sand bypassing efficiency by placing the dredged sediments further downdrift (west) of the Pass. The purpose of the demonstration was to improve the placement of sediment in a manner which maximizes the retention of material in the system, to more effectively allow sediment to transport to the downdrift beaches by placing material beyond the influence of the ebb-tidal shoal, and to minimize the return of material to the navigation channel. During the fall and winter of 2002 to 2003, approximately 400,000 cu yd of sand dredged from the navigation channel were placed in two areas on the downdrift beaches (Figure 2). About 150,000 cu yd were placed in a traditional placement area adjacent to the west jetty, and about 230,000 cu yd were placed in a new disposal area extending from 0.75 to 1.25 miles west of the west jetty. Due to real estate restrictions, the material was placed below the mean high water (MHW) line. An additional 60,000 cu yd of sand was placed on the northern section of the east jetty to inhibit flanking of the east jetty.



Figure 2. RSM disposal areas.

Monitoring plan

A monitoring plan was implemented to evaluate the behavior and movement of the material placed in the downdrift disposal areas. The intent of the monitoring plan was to gain information so that knowledgeable project management decisions could be made for determining the optimum placement of disposal material for maximum return to the littoral system.

To correlate the wave and water level forcing to the behavior of the material placed in the disposal areas and changes in the shoreline, a directional wave gage (AL001) was funded through the Mobile District's RSM program and deployed at a 30-ft depth approximately 1 mile near-shore of Perdido Pass (30.26N, 87.57W) by the U.S. Army Engineer Research and Development Center's (ERDC's) Coastal and Hydraulics Laboratory (CHL). The wave gage was deployed to provide data in near real-time through shore cable with data transmitted to CHL, and data were maintained on the gage through an internal recorded function. The wave gage was deployed in November 2001 and deployment was funded through November 2003. Due to limited funding and unsuccessful attempts to retrieve the gage, it remained deployed through 2006.

In addition to the wave and water level forcing, beach profile surveys of the shoreline adjacent to the west side of Perdido Pass and hydrographic surveys of the pass and ebb shoal were collected prior to and immediately after completion of dredging and disposal activities. Beach profiles were then conducted at 3-month intervals thereafter through August 2003. Due to the active 2004 and 2005 hurricane seasons, 2004 and 2005 lidar surveys were collected through the USACE Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. Aerial photography was accomplished prior to and following the dredging and disposal activities.

Prior to Hurricane Ivan, the area east of the pass (Florida Point) was abundantly vegetated with sea oats and other native plant species and was designated as critical habitat for piping plover, least terns, nesting sea turtles, and the Perdido Key beach mouse. Hurricane Ivan destroyed the dune fields and critical habitat. Due to the previous collaborative effort and relationships developed through the RSM Program, a multi-agency team was quickly established to plan and implement environmental restoration of the area impacted by Hurricane Ivan.

2 Effects of Hurricane Ivan

Introduction

On 16 September 2004, Hurricane Ivan made landfall 20 miles west of Perdido Pass, AL, as a category 3 hurricane with 120-mph winds (Figure 3). Nearshore waves from the storm were recorded by a bottom-mounted wave gage (AL001) located 1 mile offshore of Perdido Pass, AL. The Mobile District had first deployed the gage in November 2001, as part of a Regional Sediment Management (RSM) project. The purpose of this report is to describe the data collection methods and the comparatively rare data resulting from this hurricane event.



Figure 3. Hurricane Ivan track, AL001 gage location and storm surge estimates along Gulf Coast.

Hurricane Ivan was the strongest and longest tracked tropical cyclone of the 2004 Atlantic hurricane season. The storm we know as Ivan started out as Tropical Depression Nine on 2 September 2004 southwest of the Cape Verde Islands and finally dissipated on 24 September over southeastern Texas. It reached category 4 status on the Saffir-Simpson hurricane scale on 5 September. At this time, it was the southernmost major hurricane on record. Ivan passed just south of Grenada on 7 September and attained category 5 status in the central Caribbean Sea. Ivan passed

just south of Jamaica, the Cayman Islands, and western Cuba with winds at or just below category 5 status. It then turned northward and weakened until 0700 Greenwich Mean Time (GMT) on 16 September (2 a.m. CDT) when Ivan made landfall at Orange Beach, AL, as a category 3 hurricane with 120-mph winds and a minimum central pressure of 943 millibars. A last minute jog to the east spared the city of Mobile, AL, where winds were estimated to be only 60 knots, but the beachfront property of Gulf Shores and Orange Beach was devastated. Hurricane Ivan then continued inland, maintaining hurricane strength until it was over central Alabama. Figure 3 displays the track of the storm in relation to Perdido Pass, and the Federal Emergency Management Agency's (FEMA's) estimates of storm surge along the Gulf Coast.

Hurricane Ivan caused excessive erosion damage to the Perdido Pass project. Prior to Hurricane Ivan, the area east of the pass, known as Florida Point, was characterized as having wide beaches with well developed dune fields. Hurricane Ivan resulted in a loss of about 10 ft of elevation from the east side of the pass, destroying the dune fields and critical animal habitat.

3 Instrumentation

A Civil Tek directional wave gage (Howell 1998) was in situ, measuring waves and water levels when Ivan made landfall. This gage was named AL001 to indicate that it was the first directional wave gage deployed by ERDC in the state of Alabama. The gage was mounted in the center of a six legged, steel, trawler resistant pod that sits on the seafloor (Figure 4). Each leg of the pod has a vertically mounted pot to hold pressure transducers or other instruments. Alternate legs of the pod (painted red, green and blue in Figure 4) hold one of three pressure transducers to form an equilateral triangle 6 feet on a side. Paroscientific quartz pressure transducers, which have an accuracy of 0.01 percent, were used for the deployment. Transducers are held firmly in the colored pots using Teflon bolts. Cables run from the transducers to the gage to transmit pressure data. After the pod is lowered to the seafloor, divers jet the pod legs into the seafloor and jet in additional poles through the three pots that are not holding instruments; poles are then clamped in place to help keep the pod from moving. The pod elevation is not referenced to a datum but instead records absolute pressure at the site. The pipe visible in Figure 4 that runs between the red and green pots is used to align the compass pole to provide gage orientation after deployment. The compass is mounted on a 15-ft pole and inserted into the pipe so the orientation of the pod can be determined without the metal of the pod influencing the compass. Photographs of actual gage deployment may be found online (USACE 2007a).

The Civil Tek gage internally processes and records data. A directional Civil Tek gage, such as AL001, will hold 12-15 months of analyzed data. When the data card fills up, the gage ceases to record data so as to avoid overwriting existing data. Additionally, Civil Tek gages can optionally be set to transmit pressure time-series data to a shore station, which allows for near-real-time capability. At gage AL001, a shore station was installed and connected to the gage with approximately 4,000 ft of double armored well logging cable. The AL001 gage was originally deployed in November 2001. Maintenance trips are required to download internally recorded data and minimize bio-fouling. Such trips were performed in April 2002, March 2003, and January 2004. All three maintenance trips included retrieving the pod from the seafloor and replacing the gage and sensors.

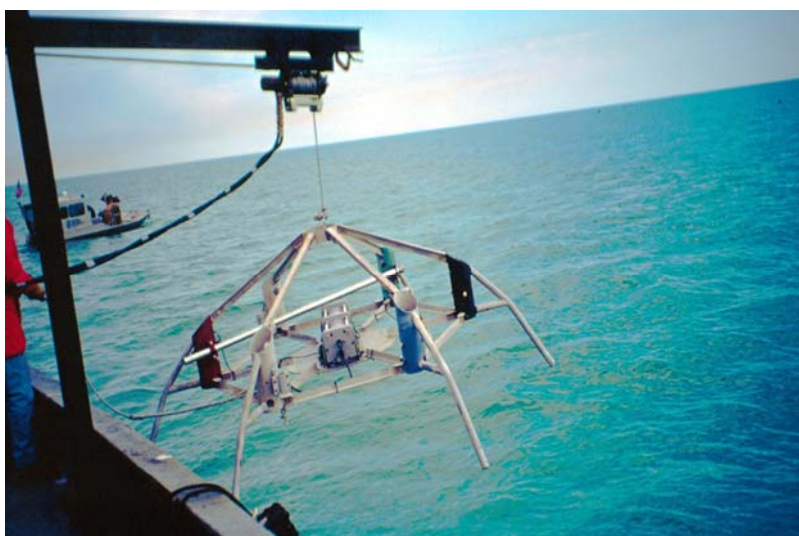


Figure 4. Typical wave gage deployment.

In late 2003, there were shore station communication problems. Therefore, beginning in January 2004, the gage was deployed in internal recording mode, with plans to return to the site and retrieve the gage and data early in 2005.

Although Hurricane Ivan occurred in September 2004, funds were not available to attempt to locate the AL001 gage until April 2005. ERDC divers failed to locate the gage. The transponder that should have pinpointed the location of the gage was not functioning and the currents were greater than 1 knot, which is too brisk to permit divers to safely perform a search to locate the gage. In the interest of safety, the retrieval effort had to be aborted. Project funding expired so the decision was made to abandon the instrument. The gage was subsequently found and salvaged by Emerald Ocean Engineering and returned to ERDC in August 2007.

4 Data Recovery and Results

The internal Civil Tek analysis reports directional wave statistics, nominal water level and directional spectra. Burst length is 30 min and the sampling rate is 1 Hz, which is pre-programmed by the operator prior to deployment. Time is recorded as GMT.

The AL001 gage data exist from 27 November 2001 through 4 December 2004, when the internal batteries expired. The historical data are available on the internet (USACE 2007b) and include some 22,800 data records. When the Civil Tek gage went on internal battery power, however, only a portion of the spectra were saved to conserve memory. Normally, the highest frequency energy reported is approximately 0.30 Hz corresponding to a period of 3.3 sec (delta frequency = $1/256$ sec, 77 frequencies) and higher frequencies are not recorded in subsurface pressure analysis for issues related to the pressure response function.

Evaluation of the directional spectra and wave statistics during Hurricane Ivan indicate that the internal Civil Tek analysis used more than the 77 frequencies reported in computing significant wave height (H_{m0}), peak period (T_p), and peak direction (D_p). T_p was 3.0 to 3.2 sec for several hours at the height of the storm. Examination of the energy spectra indicated that the pressure response function might be artificially raising the significant wave height in frequencies above 0.24 Hz. Integration of the spectral density above 0.24 Hz indicated that for this data set, at the height of the storm, wave heights with peak periods greater than 0.24 Hz are physically unrealistic because the ratio of wave height to wavelength exceeds the allowable wave steepness criteria by a factor of 2. The original data set has been maintained, however, and the spectra are post-processed to provide new directional wave statistics using a 0.24 Hz cutoff.

H_{m0} is the average of the highest one-third of the waves in the sample collected during a burst. The original data set had an H_{m0} of 7.16 m with a T_p of 3.0 sec on 16 September 2004 at 0500 GMT. The post-processed statistics showed an H_{m0} of 5.11 m with a T_p of 12.8 sec at the same time. The highest H_{m0} measured during the storm was 5.16 m at 0500 GMT on 16 September 2004 with a D_p of 159 deg True North (TN). The wave direction indicates the direction from which the waves are coming. Hurricane Ivan pounded the coastline with H_{m0} exceeding 3.0 m for 35 hr

at Perdido Pass. Water level records from the AL001 gage indicate the storm tide recorded (approximately 3 m) correlates well with the 8.8 ft recorded at the Mobile District Perdido Pass gage (Figure 3). Appendix A shows the wave statistic and spectral plots during the height of the storm. Monthly wave statistic files and plots for the entire AL001 gage deployment are available on-line (USACE 2007a and b).

5 Other Data Available

Appendix B shows the climatic summary statistics for the entire deployment period. NDBC buoy 42007 was located near the AL001 gage at 30.09°N 88.77°W. Data from this buoy corroborate data from the AL001 gage. Maximum H_{m0} recorded from NDBC buoy 42007 was 9 m with a T_p of 16.67 sec and D_p of 107 deg TN on 16 September 2004 at 0150 GMT. A barometer onboard buoy 42007 indicated a pressure drop to 974.9 millibars at 0550 GMT on 16 September 2004 when the eye apparently passed near the buoy. Appendix C shows September 2004 wave statistics and barometer plot from NDBC buoy 42007.

5 References

Howell, G. L. 1998. Shallow water directional wave gages using short baseline pressure arrays. Coastal Engineering 35:85-102.

U.S. Army Corps of Engineers. 2007a. ERDC, Coastal Hydraulics Laboratory, Field Data Collection Branch Web site:

http://sandbar.wes.army.mil/public_html/pmab2web/htdocs/alabama/perdido/perdido_pix.html.

U.S. Army Corps of Engineers. 2007b. ERDC, Coastal Hydraulics Laboratory, Field data Collection Branch, Web site:

http://sandbar.wes.army.mil/public_html/pmab2web/htdocs/alabama/perdido/perdido.html

Appendix A: Wave Summary Statistics

Figure 5 contains wave summary statistics for September 2004. Figures 6-8 are plots of the spectral density for 15 September through 16 September.

Significant wave height, H_{m0} , or wave height is the average of the highest one-third of the waves in the sample collected during a wave burst (or collection interval). In this case, the collection interval was 30 min.

Peak period, T_p , or wave period is the inverse of the frequency where the wave energy spectrum reaches its maximum.

Peak direction is the wave direction at the frequency corresponding to the peak period.

Wave direction is the direction from which the waves are coming.

Wave summary statistics (Figure 5) are displayed as time series plots showing significant wave height (meters), peak period (seconds), peak direction (degrees TN) and nominal water depth (meters). Plots are arranged in a columnar fashion so that it is easy to ascertain the all four provided values for the same time stamp. Gaps in the data occur when the data received failed quality control checks or possibly when data were simply not received for that time. All data received for September 2004 have been displayed.

Spectral density plots (Figures 6-8) provide a graphic illustration of the wave spectral energy (in 4-hr intervals) for the time preceeding and following the greatest significant wave height of the storm. The top plot displays the direction (degrees TN) by frequency (Hz) and the lower plot displays the energy (meters squared/Hz) by frequency (Hz). A listing of peak energy values may be found under the energy plot.

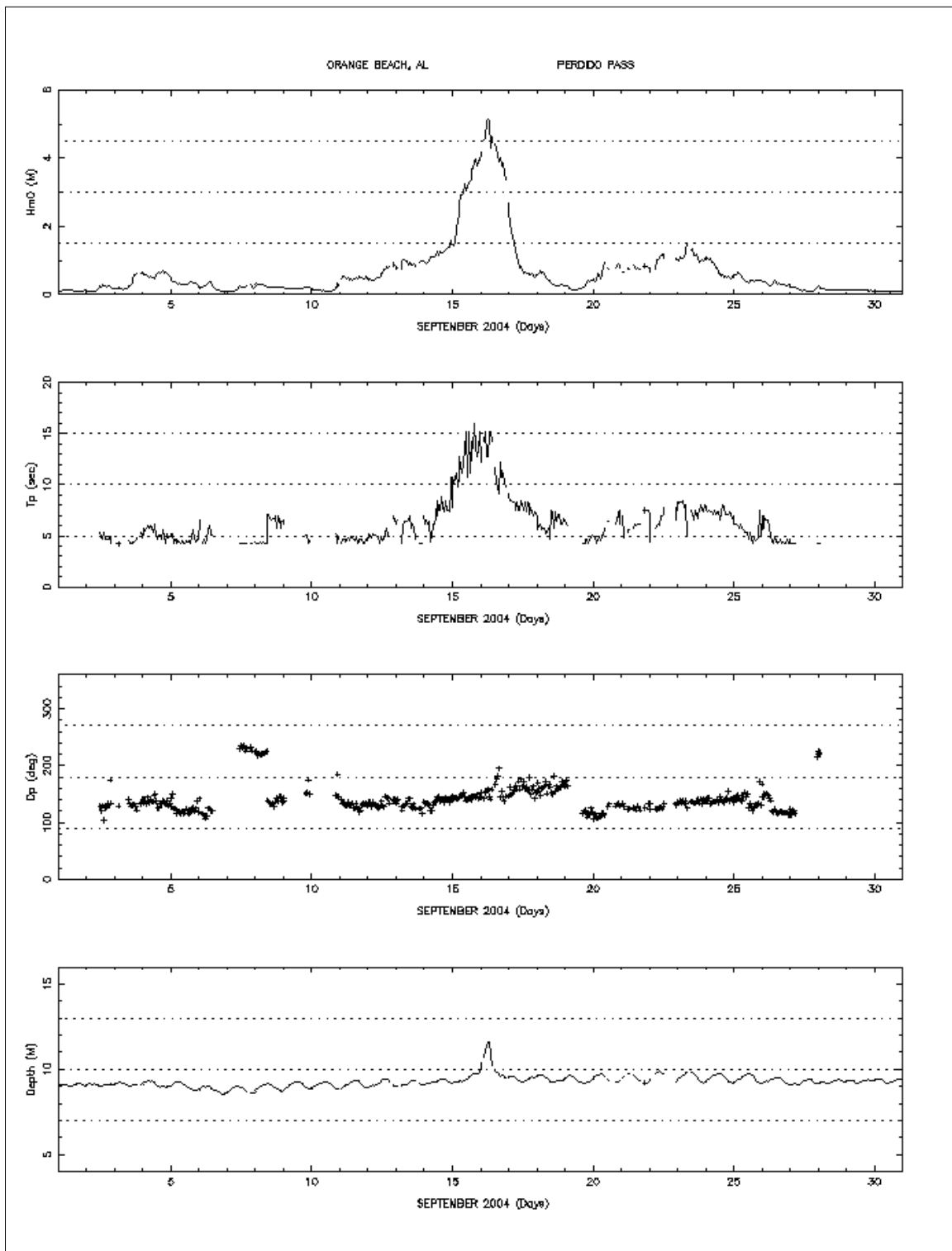


Figure 5. Wave summary statistics, September 2004.

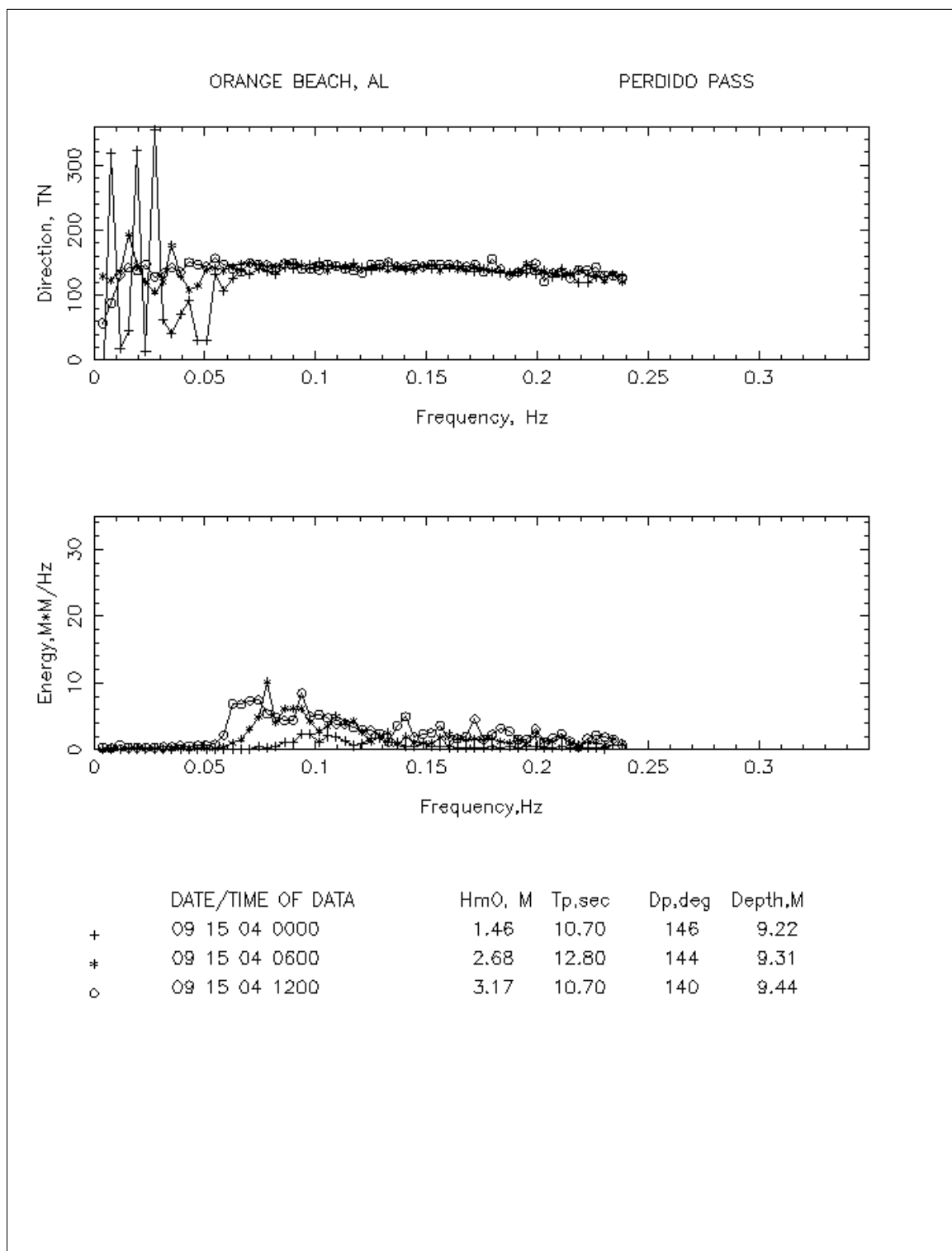


Figure 6. Spectral plot, 15 September 2004.

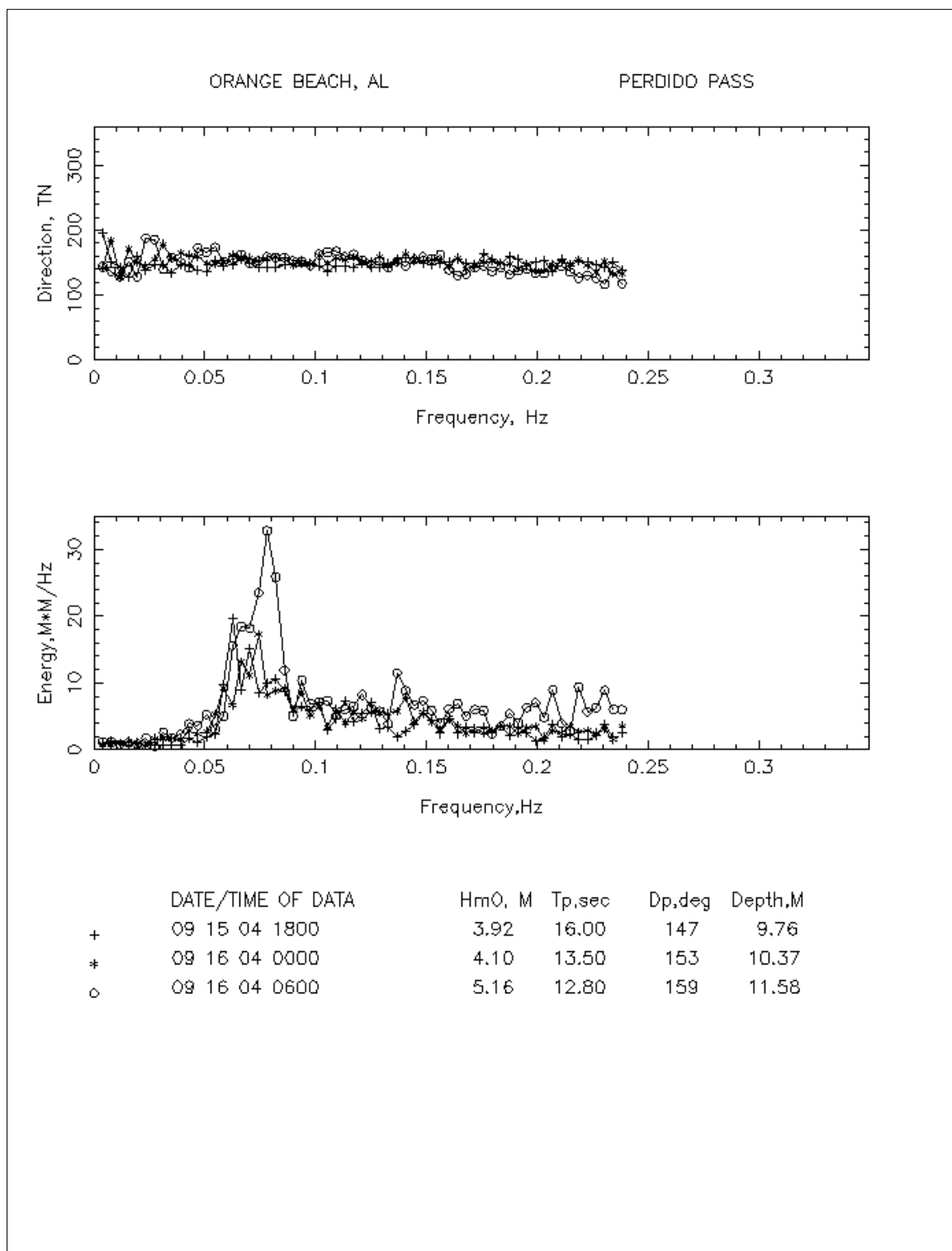


Figure 7. Spectral plot, 15-16 September 2004.

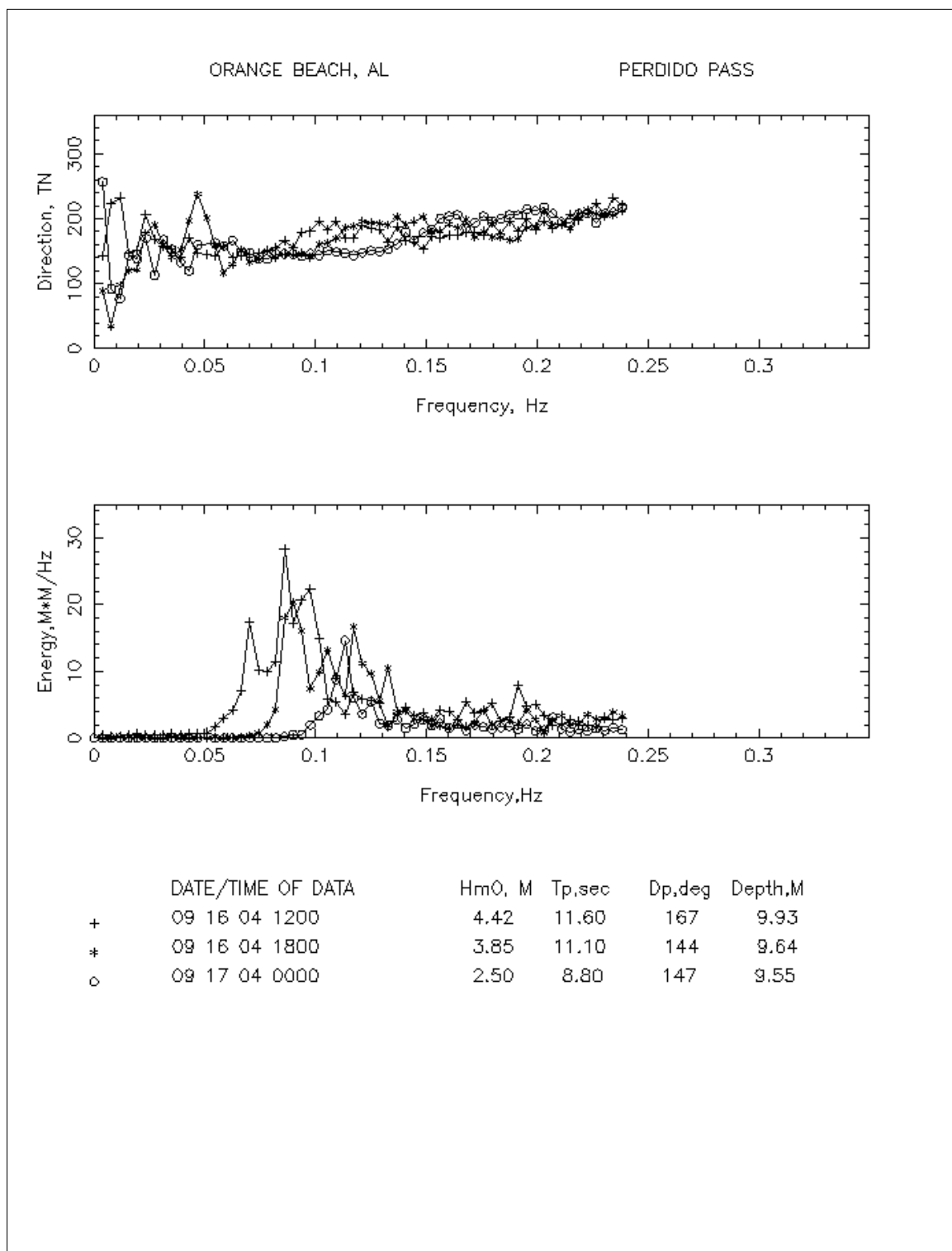


Figure 8. Spectral plot, 16-17 September 2004.

Appendix B: Summary Climatic Information

Appendix B contains summary climatic information for the entire 4-year deployment of the AL001 gage.

Significant wave height, H_{m0} , or wave height is the average of the highest one-third of the waves in the sample collected during a wave burst (or collection interval). In this case, the collection interval was 30 min.

Peak period, T_p , or wave period is the inverse of the frequency where the wave energy spectrum reaches its maximum.

Peak direction is the wave direction at the frequency corresponding to the peak period.

Wave direction is the direction from which the waves are coming.

'Number of records by month' indicates the total number of records received that passed Quality Control standards during each month of the deployment.

The 'Percent Occurrence' table gives the percentage of records (times 100) that fall into the described wave height and peak wave period categories so, to start with the data in the center of the table, 11.42 percent of the records had a wave height between 0.2 and 0.4 m and a peak period of 4.5 sec or shorter. The right hand column indicates that 48.66 percent of all the waves were between 0.2 and 0.4 m. The bottom row tells us that 16.02 percent of the waves recorded were 4.5 sec or less. From this table you can see that most of the waves recorded by the AL001 gage had a peak period between 5.6 and 7.9 sec and a significant wave height between 0.2 and 0.4\ m.

The Mean H_{m0} table gives the average of each month's wave's heights.

The Largest H_{m0} table gives the height of the highest wave recorded in each month.

The 4-year statistics summarize the statistics for all four years of the gage deployment including:

Mean (average) height and period of all waves.

Most frequent direction from which the waves came.

Standard deviation of both wave height and wave period.

Statistics associated with the highest wave recorded; the wave height, wave period, the direction from which it came and date of occurrence. The date is in the format `yyyymmddhh` where `y` = year, `m` = month, `d` = day, and `h` = hour.

PERDIDO PASS, AL (AL001)													30.26N 87.57		
NUMBER OF RECORDS BY MONTH FOR 2001 - 2004															
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL		
2001	0	0	0	0	0	0	0	0	0	0	77	744	821		
2002	744	672	744	717	744	720	744	744	720	744	720	197	8210		
2003	0	0	149	720	610	660	691	744	698	313	625	744	5954		
2004	719	694	744	463	744	720	744	744	720	744	720	75	7831		
PERDIDO PASS, AL (AL001)													30.26N 87.57	IRRESPECTIVE OF DIRECTION	
2001-2004															
PERCENT OCCURRENCE(X100) OF HEIGHT AND PERIOD															
HEIGHT (METRES)														PEAK PERIOD(SECONDS)	TOTAL
	SHORTER-	4.5	4.6-	5.6-	8.0-	10.7-	11.6-	12.8-	14.2-	16.0-	18.3-				
		4.5	5.5	7.9	10.6	11.5	12.7	14.1	15.9	18.2	LONGER				
0.20-0.40		1142	850	2264	593	13	4	.	.	.	.		4866
0.50-0.90		439	730	1597	176	4	.	.	.	.	.		2946
1.00-1.40		21	74	475	147	4	.	.	.	.	.		721
1.50-1.90		.	1	108	74	4	.	.	.	.	.		187
2.00-2.40		.	.	19	44	3	.	.	.	.	.		66
2.50-2.90		.	.	6	9	1	.	1	.	.	.		17		
3.00-3.40		.	.	1	4	3	1	2	.	.	.		11		
3.50-3.90		.	.	.	3	2	3	3	.	.	.		11		
4.00-4.40		.	.	.	.	.	1	.	.	.	.		1
4.50-4.90		.	.	.	.	.	.	.	1	.	.		1
5.0+		.	.	.	.	.	.	.	.	.	.		0
TOTAL		1602	1655	4470	1050	34	9	6	1	0	0				
COUNT OF Hm0 LESS THAN .2 M= 0.														PERCENT(X100) OF Hm0 LESS THAN .2 M= 1142.	
MEAN Hm0 (M)= 0.5 LARGEST Hm0 (M)= 5.2 MEAN TP (SEC)= 6.0 TOTAL CASES= 22378.															

Figure 9. Climatic summary statistics (continued).

MEAN H_{m0} (METRES) BY MONTH AND YEAR													
PERDIDO PASS, AL (AL001) (30.26N 87.57)													
MONTH													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
YEAR													MEAN
2001	.	.	.	.	.	.	.	.	.	.	1.6	0.6	0.7
2002	0.6	0.5	0.6	0.5	0.5	0.4	0.3	0.4	0.8	0.5	0.4	0.3	0.5
2003	.	.	0.4	0.5	0.6	0.6	0.5	0.4	0.4	0.5	0.6	0.6	0.5
2004	0.5	0.6	0.6	0.6	0.6	0.5	0.3	0.3	0.7	0.5	0.7	0.3	0.5
MEAN	0.5	0.6	0.6	0.5	0.6	0.5	0.4	0.4	0.6	0.5	0.6	0.5	
LARGEST H_{m0} (METRES) BY MONTH AND YEAR													
PERDIDO PASS, AL (AL001) (30.26N 87.57)													
MONTH													
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
YEAR													
2001	.	.	.	.	.	.	.	.	.	.	2.8	2.2	
2002	3.7	2.5	2.5	2.2	1.1	0.9	0.9	1.4	4.0	2.4	1.6	1.1	
2003	.	.	0.9	1.5	1.4	2.3	3.2	1.8	1.1	1.4	2.6	2.2	
2004	2.2	1.8	1.8	1.5	1.7	2.1	0.9	1.2	5.2	2.4	2.3	1.1	
4 YR. STATISTICS FOR PERDIDO PASS, AL (AL001) (30.26N 87.57)													
THE MEAN SIGNIFICANT WAVE HEIGHT (METRES) =												0.5	
THE MEAN PEAK WAVE PERIOD (SECONDS) =												6.0	
THE MOST FREQUENT 22.5 (CENTER) DIRECTION BAND (DEGREES) =												157.5	
THE STANDARD DEVIATION OF H_{m0} (METRES) =												0.4	
THE STANDARD DEVIATION OF TP (SECONDS) =												1.6	
THE LARGEST H_{m0} (METRES) =												5.2	
THE TP (SECONDS) ASSOC. WITH THE LARGEST H_{m0} =												12.8	
THE PEAK DIRECTION (DEGREES) ASSOC. WITH THE LARGEST H_{m0} =												159.0	
THE DATE OF LARGEST H_{m0} OCCURRENCE IS												2004091606	

Figure 9. (Concluded).

Appendix C: Wave Summary Statistics and Barometric Pressure

Appendix C contains wave summary statistics and barometric pressure for NDBC buoy 42007 for September 2004. Summary statistics are displayed as time-series plots showing significant wave height (meters), peak period (seconds), peak direction (degrees TN) and barometric pressure (millibars). Plots are arranged in a columnar fashion so that it is easy to ascertain the all four provided values for the same time stamp.

Detailed information about NDBC buoy 42007 may be found by visiting <http://www.ndbc.noaa.gov> and navigating to the Web page for this buoy.

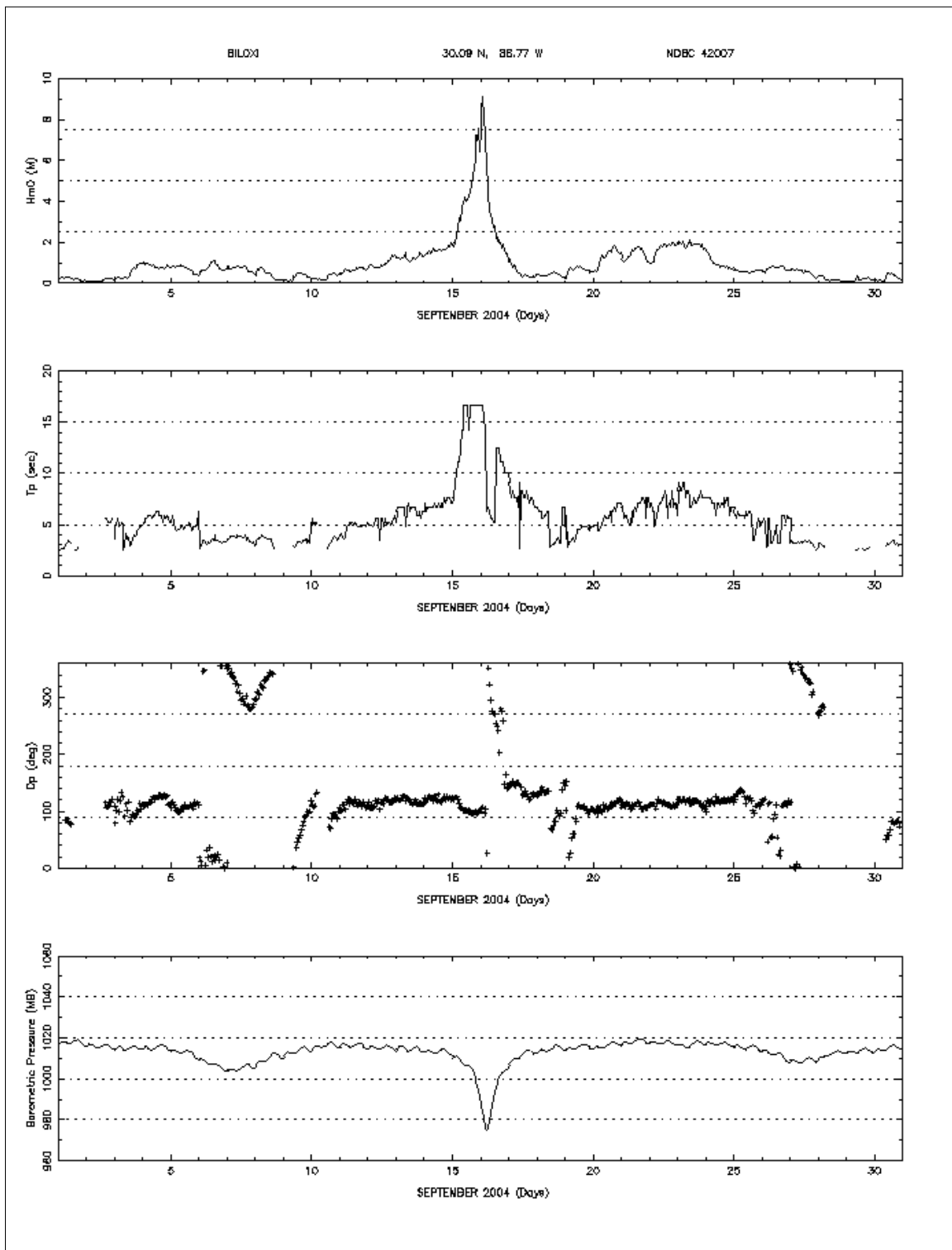


Figure 10. Wave statistics and barometer plot from NDBC buoy 42007.

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14. ABSTRACT In November 2001, the U.S. Army Engineer District, Mobile, funded the Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center (ERDC) to deploy a bottom mounted wave gage in 30 ft of water approximately 1 mile offshore of Perdido Pass, AL. On 16 September 2004, Hurricane Ivan made landfall 20 miles west of Perdido Pass as a category 3 hurricane with 120 miles-per-hour maximum winds. The gage was located and recovered in August 2007 by Emerald Ocean Engineering and returned to ERDC, and the data were found to be intact. Nearshore waves from Hurricane Ivan were recorded by the wave gage. Highest significant wave height of 5.11 m occurred at 0500 GMT on 16 September 2004, with a peak period of 12.8 sec.					
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SUBJECT TERMS

Civil Tek
Climatic summary
Energy spectra
Hurricane
Ivan
Peak period
Peak direction
Perdido
Regional Sediment Management
Significant wave height
Spectral density
Wave gage